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An Evaluation of Head Movement in Backboard-Immobilized Helmeted Football, Lacrosse, and Ice Hockey Players

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Objective: Improper handling of an unstable neck injury in the prehospital setting may result in iatrogenically induced neurologic injury. Due to helmet design, stabilization of the cervical spine in American football does not require routine removal of the helmet and shoulder pads prior to transport. Adequate data is not available evaluating hockey and lacrosse helmets. This study compares the amount of head movement in American football, lacrosse, and ice hockey helmets during head and neck stabilization procedures.

Study Design: Prospective.

Participants: 12 ice hockey, 9 football, and 9 lacrosse athletes from an National Collegiate Athletic Association Division 1 program.

Setting: On-campus biomechanical laboratory with three HiRes cameras, routinely tested for accuracy.

Methods: Athletes were immobilized on backboards as per protocol. Three motion analysis HiRes cameras follow retroreflective markers placed on the helmet and bite mouthplate to measure relative head and helmet motion.

Main Outcome Measures: Helical angles determine the relative range of motion of the head inside the helmets.

Results: The mean range of head motion for football players was 4.88° ($n = 9$, SD 2.07), lacrosse players 6.56° ($n = 9$, SD 1.61), and ice hockey players 5.54° ($n = 12$, SD 1.19). These results were not significantly different ($p > 0.05$).

Conclusions: The rotational head motion seen inside standard immobilized lacrosse and ice hockey helmets is similar to that seen in football helmets. This supports the safety of prehospital stabilization of the potential cervical spine-injured ice hockey and lacrosse athletes with in-line stabilization and helmet in place. Extrapolation of data may not be applicable to other helmet designs, and future studies are needed to determine the safety of emergency procedures in all helmet designs.

Key Words: Helmet removal—Cervical spine—Football—Lacrosse—Ice hockey—Injury.

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INTRODUCTION

Improper handling of an unstable neck injury may result in potential iatrogenically induced neurologic injury. Stabilization of the cervical spine in American football does not require routine removal of the helmet and shoulder pads prior to transport. The unique characteristics of the well-fitted football helmet allow prehospital personnel to safely stabilize the helmeted athlete for transport. By stabilizing the helmet, the close-fitting design allows adequate stabilization of the head inside the helmet. This in turn will stabilize the neck in the event of a potential cervical spine injury, preventing iatrogenic progression of the injury. Data regarding the safety of hockey and lacrosse helmet removal is limited. The design of ice hockey and lacrosse helmets differs significantly from that of football helmets, and results from studies performed on other helmets may not be applicable to all helmet designs. Hockey and lacrosse shoulder pads are generally less rigid and of lower profile than are football shoulder pads, and the helmets fit less securely than do football helmets. This study evaluates the amount of head movement inside the immobilized helmet in football, lacrosse, and ice hockey with controlled head and neck stabilization procedures in place.

METHOD

Thirty volunteer collegiate athletes ($n = 9$ football, $n = 12$ ice hockey, $n = 9$ lacrosse) from the University of Delaware were studied. All athletes used the same brand (football: Bike Air/Schutt Athletics, Litchfield, OH, U.S.A.; lacrosse: Sport Cascade/Sport Helmets, Liverpool, NY, U.S.A.; ice hockey: CCM/Sport Maska, Inc., Westmount, Quebec, Canada) and size equipment worn while competing during the collegiate season. None of the volunteers had any history of cervical spine injury or pathology. All volunteers were examined prior to the trials by the principal investigator (K.W.) and found to have full cervical spine motion without pain or limita-

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tions. Helmets were fitted by full-time experienced equipment managers to ensure proper fit. All subjects were immobilized in a supine position to a standard spine backboard with straps and lateral foam pads attached to the backboard to secure the head in a neutral position as per protocol.[1] No cervical collar was used in this protocol. Three retroreflective markers were attached to the helmet, and three markers were attached to a rigid Plexiglas core mounted inside of the mouthpiece (Fig. 1 and 2). The markers enabled independent measurement of the helmet and head with six degrees of freedom. Subjects were instructed to maintain constant bite pressure on the 32-gram mouthpiece to prevent jaw motion and to ensure that the markers were fixed to the skull. Three Motion Analysis HiRes cameras (Motion Analysis Corp., Santa Rosa, CA, U.S.A.) operating at 240 Hz recorded marker motion. Marker positions in three-dimensional space were calculated using Motion Analysis EVa software, and smoothed with a second-order low-pass Butterworth filter at a cutoff frequency of 10 Hz. Marker accuracy inside of the calibrated volume was determined to be better than 0.5 mm along all three axes.[2] Marker positions were used to determine local coordinate systems (rotation matrices) for the head and helmet. The relative helical axis (RHA), consisting of a unit vector and angle, was derived from the rotation matrices to determine the position of the head with respect to the helmet in each frame of data.[3] The RHA was then resolved into its component parts in the global coordinate system, and the component corresponding to the longitudinal axis of the subject was extracted for analysis. Measurements were obtained during the period when the backboard was perturbed a constant 12° about its long axis in order to simulate jostling that may occur during transportation. Consistent perturbation of the backboard was accomplished by allowing the edge of the board corresponding to the subject's left side to fall freely to a sudden stop for approximately 8.9 cm, resulting in approximately 12° of motion about the long axis of the subject. Subjects were not aware of the exact moment that free-fall was initiated. The relative motion between the head and helmet about the longitudinal axis of the subject was then analyzed to determine the maximum amount of movement that occurred in each trial. The range of motion of the head inside the helmet was extrapolated from the difference between head motion and helmet motion. Five separate trials were obtained for each athlete (n = 150 trials), and results were averaged within subjects. The averaged values for each subject were subsequently analyzed using a one-way analysis of variance with Neuman-Keuls post hoc test. The investigator (J.R.) was blinded to the sport and subject identity when interpreting the data. The University of Delaware Human Studies Committee approved the study. Consent was obtained prior to the study.

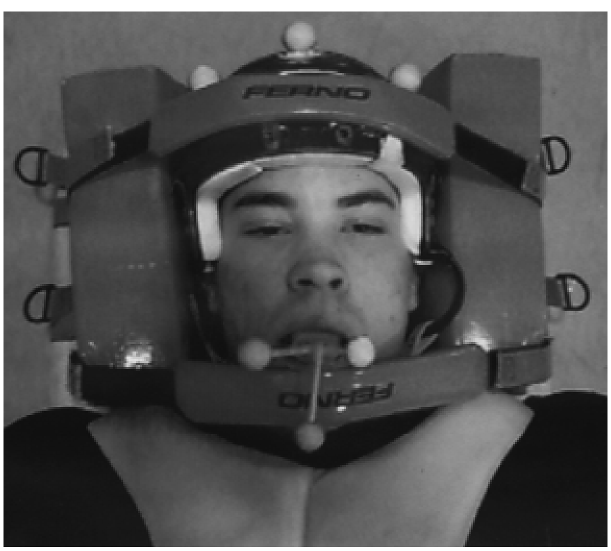

FIG. 1. Picture of study subject (hockey). The retroreflective markers attached to the helmet and the Plexiglass core mounted inside the mouthpiece are easily visualized.

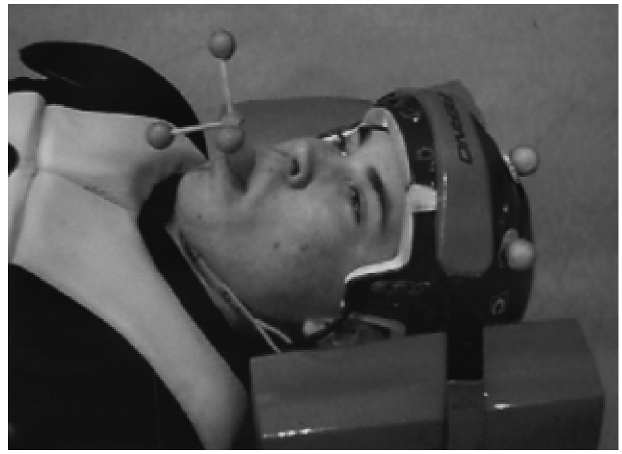

FIG. 2. Picture of study subject (side view).

RESULTS

The mean range of head motion for football players was 4.88° (n = 9, SD 2.07), lacrosse players 6.56° (n = 9, SD 1.61), and hockey players 5.54° (n = 12, SD 1.19). These results were not significantly different ($p > 0.05$).

Head and helmet position in global space were averaged about the longitudinal axis of the subject (Fig. 3).

DISCUSSION

Cervical spine trauma in sports is an uncommon but devastating injury. Improper handling of an unstable neck in the prehospital setting may result in potential iatrogenic neurological injury.[6,10] On-field personnel must use proper handling techniques in order to minimize neurologic sequelae, expedite treatment, and prepare the athlete for transportation to the hospital.[4,5] There has been considerable debate over protocols established for removal of equipment during the on-field management of helmeted athletes with suspected neck injury.[12] There is the potential for spinal instability following cervical spine trauma, and full assessment of the cervical

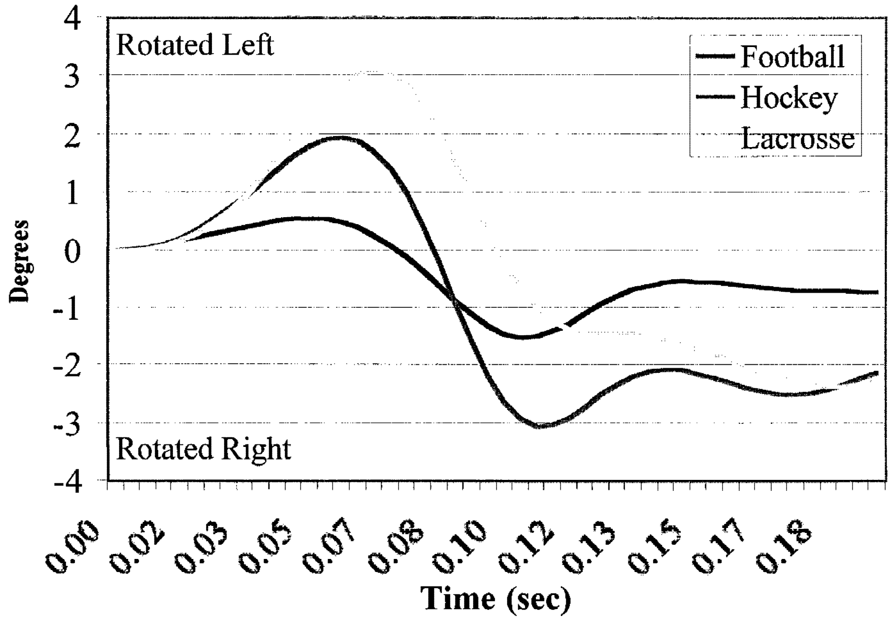

FIG. 3. Average head orientation relative to the helmet about the long axis of the board. The graph starts approximately 0.03 seconds prior to the free-fall period. The *x*-axis is time in seconds, and the *y*-axis is the amount of relative head motion in degrees.

spine is difficult in the prehospital setting.[6–10,12] The goal for emergency management of these injuries is the safe expeditious transport of the injured player to a medical facility with radiographic capabilities. The protective helmet and shoulder pads worn by the athlete may complicate the immobilization process and introduce special considerations.[9] Consensus on the need or advisability of removing protective gear during the initial assessment has not been reached.[11,12]

Several studies have looked at the helmet in American football. No study supported removal of the football helmet or shoulder pads in the prehospital setting.[9,13–18] Some authors advocate helmet removal without differentiating among types of helmets.[19–21] Adequate data is limited evaluating helmets in hockey,[15,22–27,43] lacrosse,[28,42] rugby,[29–32] equestrian,[33] baseball/softball, kayak, skiing/snowboarding,[34] bicycle,[35,36] or skateboard/roller skating/in-line skating,[37] and results from studies evaluating motorcycle[13,14,19,38] and football[9,13–17] helmets may not be applicable to other helmet designs. The biomechanics of football,[39] hockey,[40,41] and lacrosse[42] equipment have been investigated. Although the alignment and immobilization of the cervical spine with football equipment has been described and is well accepted, only a few studies have investigated helmet removal in hockey,[15,22,23,25–27,43] and no study looks specifically at lacrosse helmets. Compared to football, hockey and lacrosse helmets fit less securely, and shoulder pads are generally less rigid and of lower profile. Several studies assessing the relative position of the cervical vertebrae during helmet removal in hockey concluded that helmet removal significantly alters cervical alignment with shoulder pads in place.[15,23,25–27,43] Their conclusions were similar to studies with football helmets[9,16] and recommend that the helmet not be removed in the prehospital setting without simultaneous removal of the shoulder pads.[15,23,25–27,43] The question remains whether the looser fit of the ice hockey and lacrosse helmets, along with the thinner shoulder pads compared with football, will allow adequate neck and head stabilization for safe immobilization and transport. One study found that hockey players secured to the backboard were able to flex, extend, and laterally rotate their necks much more than expected, concluding that immobilization of the hockey helmet to the backboard may not provide adequate stabilization of the cervical spine.[43]

TABLE 1. *Range of motion by helmet type*

Table 1	Ice hockey	Football	Lacrosse
N	12	9	9
Mean	5.54	4.88	6.56
SD	1.191	2.067	1.611
$P < 0.05$	No	No	No

The results of this study show that the amount of head movement inside an immobilized lacrosse and ice hockey helmet is minimal, when compared with movement within a football helmet. The tight-fitting football helmet allowed less than 5° of head movement inside the helmet with BTLS immobilization. The looser-fitting helmet designs of lacrosse and ice hockey had slightly greater but statistically nonsignificant ($p > 0.05$) head movement inside the helmet compared with the football helmet with helmet and shoulder pads in place. Studies show that control of the motion of the head is necessary for neck stabilization.[44] The amount of head or neck motion that is safe when transporting a helmeted athlete has not been well established. When one limits head motion, this will extrapolate to decreased neck/spine motion. Although this is theorized, this study does not directly address neck/spine motion, only head motion.

Several study limitations must be noted when considering this data. The retroreflective markers positioned on the helmet and bite mouthpiece (Fig. 1 and 2) measure the amount of head motion inside the helmet. Actual movement of the cervical spine could not be measured directly by this study design. Control of head motion is required for proper cervical spine stabilization.[44] This study design compares the head motion in hockey and lacrosse with a standard football helmet. The control of head motion in hockey and lacrosse was found to be similar to that in football helmets. None of these helmet designs drop low enough to control neck movement. Whether control of motion of the head can be extrapolated to be an accurate indicator of cervical spine movement may be debated. Taking into account the present state of literature, hockey and lacrosse helmets may stabilize the neck as well as football helmets, with shoulder pads in place. Further study is needed to confirm that stabilization of head motion will extrapolate to similar control of potentially dangerous neck motion.

This study measured head motion relative to the helmet. No measure of actual neck/spinal movement was performed in this protocol. Helmet designs are not designed to limit neck/spine movement. The purpose of this study was to investigate whether different helmet designs would limit movement of the head. It has been noted previously that control of the motion of the head is necessary for neck stabilization.[44] By deductive reasoning, if present stabilization methods are successful in controlling head motion in football-, lacrosse-, and ice hockey-helmeted athletes, then this may also effectively control neck/spine movement. Further study designs that specifically look at neck/spine movement in the helmeted athlete will be needed to confirm these assumptions.

This study was performed on healthy adult college-age male subjects. The injured athlete with a cervical spine injury may have protective muscle spasms that stabilize and further limit neck motion. In noninjured volunteer subjects, movement of the head and neck may be greater than in actual patients with cervical spine injury. One also cannot necessarily extrapolate these conclusions to a female or younger population without further study.

The subjects studied were tested using the same equipment used during the intercollegiate season. There is no reason to suspect data accumulated with these helmets would not be extrapolated to different brands of similar well-fitted helmet designs. Studies evaluating football helmets and neurotrauma found no particular helmet was associated with a disproportionate number of concussions or cervical spine injuries.[45]

Experienced personnel fitted all helmets in this study. It is not known if poorly fitting hockey helmets contribute to cervical spine injuries,[46] as has been suggested in football.[12] A poorly fitting hockey or lacrosse helmet may favor flexion of the neck after impact, and a helmet that is too loose or too lightly padded may fail to reduce the forces on the neck resulting from a collision.

No cervical collar was used in this protocol.[47] Some authors suggest that to prevent the possible flexion and extension of the cervical spine in the helmet, a hard or soft cervical collar should be used around the neck during transport.[43] It is often difficult to achieve proper fit for cervical collars in helmeted athletes, as the helmet and shoulder pads may interfere with proper positioning of the collar. During the pilot study, this was found to be true, as proper immobilization techniques were hindered by collar placement. Cervical collars are not in universal practice in the prehospital care of the helmeted athlete.[48] Proper immobilization with attachable commercially available cervical binders (as used in this study) (Fig. 1 and 2), taping or strapping,[10,49] and sandbags[12,43,48] can be used without collar placement if equipment precludes proper placement of a collar. Other forms of cervical immobilization have been studied.[50] Tape and a Velcro strap were used to stabilize the helmet to the backboard. The nonhelmeted head taped to the backboard directly over the eyebrows has been shown to reduce most lateral and bending motions.[10] This has not been well studied in the helmeted athlete.

Prehospital medical personal and sports medicine teams should formulate a plan in advance to prepare for unexpected clinical scenarios such as cervical spine injuries, and skills such as face mask and helmet removal in different sports should be practiced.

CONCLUSIONS

While there have been reported cases of iatrogenic neurological progression of cervical spine injuries in nonathletes, no such injuries have been reported in properly handled helmeted athletes from the policy of keeping the helmet in place.[12] As with helmeted American football, helmets and shoulder pads should not be removed in the prehospital management of the hockey or lacrosse player with a potential cervical spine injury unless absolutely necessary. If required, both helmet and shoulder pads should be removed simultaneously. The strength of the evidence is relatively circumstantial and somewhat anecdotal,[12] but the few related studies have shown that helmet removal in the cervical spine-injured player may be risky. The need to remove the helmet in the prehospital setting has not been established. No injuries have been reported from the policy of keeping the equipment in place. This study supports the policy of stabilization with helmet and shoulder pads in place in football, ice hockey, and lacrosse helmets. The amount of movement that is safe to prevent iatrogenic injury has yet to be determined. Whether these thoughts can be extrapolated to other helmet designs or to the female or pediatric population has yet to be established.

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